"BLAST AND FRAGMENT LOADING ON CONTAINMENT STRUCTURES"

- A MANUAL OVERVIEW

By

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ABSTRACT

A manual was prepared to aid the government in designing an explosion
containment structure (ECS) to be used for the demilitarization of chemical
munitions. Other manuals are available for the prediction of blast and frag-
ment loadings; however, these are directed toward bare explosives and con-
ventional munitions. Chemical munitions combine the non-ideal effects of
casing, chemical agent around the charge, and non-spherical charge shape.
This manual was prepared to direct the user on the procedures to be followed
to predict the blast and fragment loading from chemical munitions. Specifi-
cally, the loadings are those to be used in the design of an ECS in a demil-
itarization facility. During the preparation of this manual, tests were
performed at NSWC, Dahlgren, Virginia, to supplement the very limited pre-
vious data base for both blast and fragments and to confirm the applicabil-
ity of the prediction procedures presented here. The munitions tested are
those planned for demilitarization at Johnston Island (JI); however, the
manual is written to be general for all chemical munitions and demilitari-
zation facilities.

ACKNOWLEDGEMENTS

INTRODUCTION

A variety of manuals are available for determination of blast and fragment loads applied to structures when a high explosive material detonates inside an enclosure. The prediction methodologies presented in these manuals are applicable to a wide variety of explosive sources. In addition to the wealth of information collected on high explosive materials alone, numerous investigations into the blast and fragmentation properties of munitions which contain high explosives have been conducted, quantified, and included in the technical manuals. In the past, munitions which contained a large part of their total weights as high explosive material were or primary interest to hazards researchers and weapons designers. These munitions often are designed to produce a dangerous blast field and project high velocity fragments. Chemical weapons have different characteristics. The explosives inside chemical weapons serve only to rupture the casing and disperse the chemical agent. The generation of a dangerous blast field or projection of hazardous fragmentation by chemical weapons has never been a design goal. Thus, extensive testing to characterize these parameters has, in the past, never been pursued and no significant data base has been developed from which to quantify the blast and fragmentation of chemical weapons. Consequently, it was unknown whether existing manuals which present prediction methodologies based on data for bare explosives and conventional munitions could be used with confidence to quantify the hazards associated with the detonation of chemical munitions. This uncertainty conflicts with the confidence one desires in explosion containment structure (ECS) design and was the reason for developing a manual aimed specifically at chemical munitions.

During the preparation of this manual, tests were performed at the Naval Surface Weapons Center (NSWC) to supplement the very limited previous data base for both blast and fragment data and to confirm the applicability of the prediction procedures presented herein. Beyond this, the prediction methodologies are applied to a variety of ECS configurations, and conceptual designs of several containment structures are compared.

The manual is organized into two voluems. Volume I includes the chapters presented below. In the chapters, numerous calculations are referenced to support conclusions. These calculations, along with concept design calculations are included in Volume II. Reference is made throughout the manual

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to the proper location in the calculation appendices for user cross-reference.

Chapter	Topic
1	Introduction
2	Fragmentation
3	Blast and Fragment Load Estimation Procedures
4	ECS Loading
5	Evaluation of ECS Configurations
6	Candidate ECS Conceptual Designs

This manual develops techniques which are general in nature and can be applied to a variety of chemical demil facilities. However, the majority of the analysis and related testing is very applicable to the Johnson Atoll Chemical Agent Disposal System (JACADS) the design of which is currently under development. Blast and fragment loads used in the design of this system are predicted using the subject manual. This work was completed under the technical direction of the U.S. Army Toxic and Hazardous Materials Agency (USATHAMA) and the U.S. Army Corps of Engineers, Huntsville Division (USAEDH) under contract number DACA87-81-C-0099. Copies of this manual should be requested through these organizations.

Chapter 2 - Fragmentation

This chapter contains the following subjects:

1) Empirical prediction models for conventional (nonchemical) munitions.
2) A review of current published literature and data pertaining to chemical munition fragmentation studies.
3) Application of prediction models to specific chemical munitions.
4) Comparison of predictions to arena test data.
5) Estimates of the worst case fragment threat, based on analysis of NSWC arena test data, for the M426 projectile, M55 rocket, and M23 mine.

A considerable amount of work has been done to develop analytical models for predicting the fragmentation characteristics of conventional munitions loaded with high explosives (HE). However, all typical prediction models assume that the HE is in intimate contact with the munitions wall or case. To our knowledge, very little work had been done to develop fragmentation

prediction models for munitions where HE is separated from the munition wall by a chemical agent, or other fluid. The purpose of this chapter was to fill this gap and to identify "worst case" fragments of specific chemical weapons.

The following parameters must be known of a fragment at impact to determine the relative damage potential to a given target: velocity mass, shape, orientation, and material properties. Standard prediction methodologies exist for the calculation of fragment velocity and mass distributions for conventional cased munitions. These methodologies were adapted to chemical munitions by including the mass of the chemical agent and burster wall in the computational procedures. Use of the modified procedures was compared to test data collected during preparation of this manual and some data that existed previously.

The reader is cautioned several times in the manual that one should choose test data, if available and of good quality, to make his determination of the worst case fragment emanating from the detonation of a given chemical munition, over the results obtained from the analytical procedures. This suggestion is based on a literature review of arena test data on the M122, M426, M55, and M23 chemical munitions, and on arena tests conducted by NSWC, Reference 1. The data base was very limited, except for the M121 projectile. The data base for the M426 projectile and M55 rocket were very limited, and no test data were available for the M23 mine.

Due to the limited data base, additional arena tests were conducted at NSWC. The test program was divided into two phases. The purpose of Phase was to determine:

a) Fragmentation patterns

b) Orientation of munitions and velocity screens for Phase II tests.

c) Location of fragment recovery bundles for Phase II tests.

The test setup for Phase I included 360° of steel witness plates and camera coverage. The Phase II tests were the actual arena tests. Three rounds each of the M426 projectile, the M55 rocket, and the M23 mine were detonated to generate fragment dispersion into the wallboard recovery media. Fragments were recovered and weighed after the third shot for each type munition. The munition orientation and wallboard locations are illustrated in Figures 1 through 3. Blast measurements at the locations identified in Figures 2 and 3 were made to provide blast data. Each wallboard was divided into five

Figure 1. Chemical Munitions Program -- M23 Land Mine Fragment Recovery
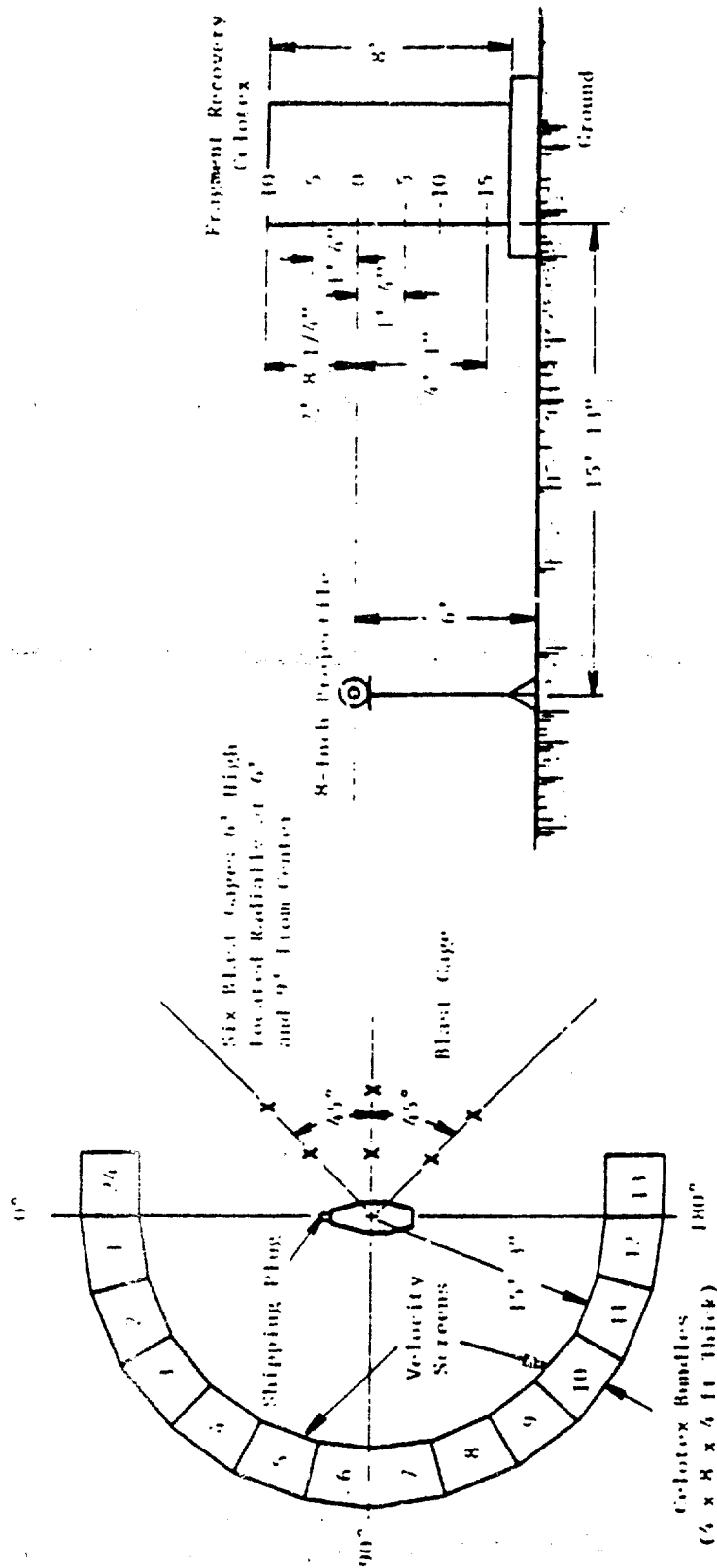
Figure 2. Chemical Munitions Program -- 8-Inch Chemical Projectile Fragment Recovery

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Figure 3. Chemical Munitions Program -- 115 mm Chemical Rocket Fragment Recovery

zones, as illustrated in Figure 4. Velocity screens were placed at various zone locations on the wallboard recovery media in an attempt to relate recovered fragments to the measured velocities. Of course, more than one fragment penetrated each screen, but this still resulted in a method of identifying groups of fragments to a velocity.

The modified analytical procedure for prediction of fragment mass and velocity distributions agreed reasonably well with test data for chemical munitions of regular, simple geometry such as the M122 and M426 projectile. These computations did not correlate as well, however, with the M55 rocket or M23 mine arena test data. The M55 rocket and M23 mine both had more complex geometries, and the rocket was cased of aluminum instead of steel, and the mine had assymetrical charge positions. The fragment breakup pattern of chemical munitions was similar to that obtained from bursting pressure vessels, fragments having great variability in shape.

A safety factor is commonly used to determine blast loads for design of blast-resistant structures. A typical safety factor is to increase the effective charge weight by 25 percent. It is recommended that a safety factor not be used in fragmentation calculations, regardless of whether the worst case fragment is analytically or experimentally determined because the criteria for selection of worst case fragment and penetration calculations are conservative; hence, a built in safety factor is obtained.

Chapter 3 - Blast and Fragment Load Estimation Procedures

A review of existing manuals and documents concerned with air blast loading and fragmentation loading (penetration capability) is provided to direct the user to additional background information. The first responsibility of the chapter is to give blast prediction techniques. A general discussion of air blast phenomenology and scaling is presented along with prediction curves for air blast loading. As examples Figures 5 and 6 can be used to determine blast pressure and specific impulse at scaled distances about a plate surface.
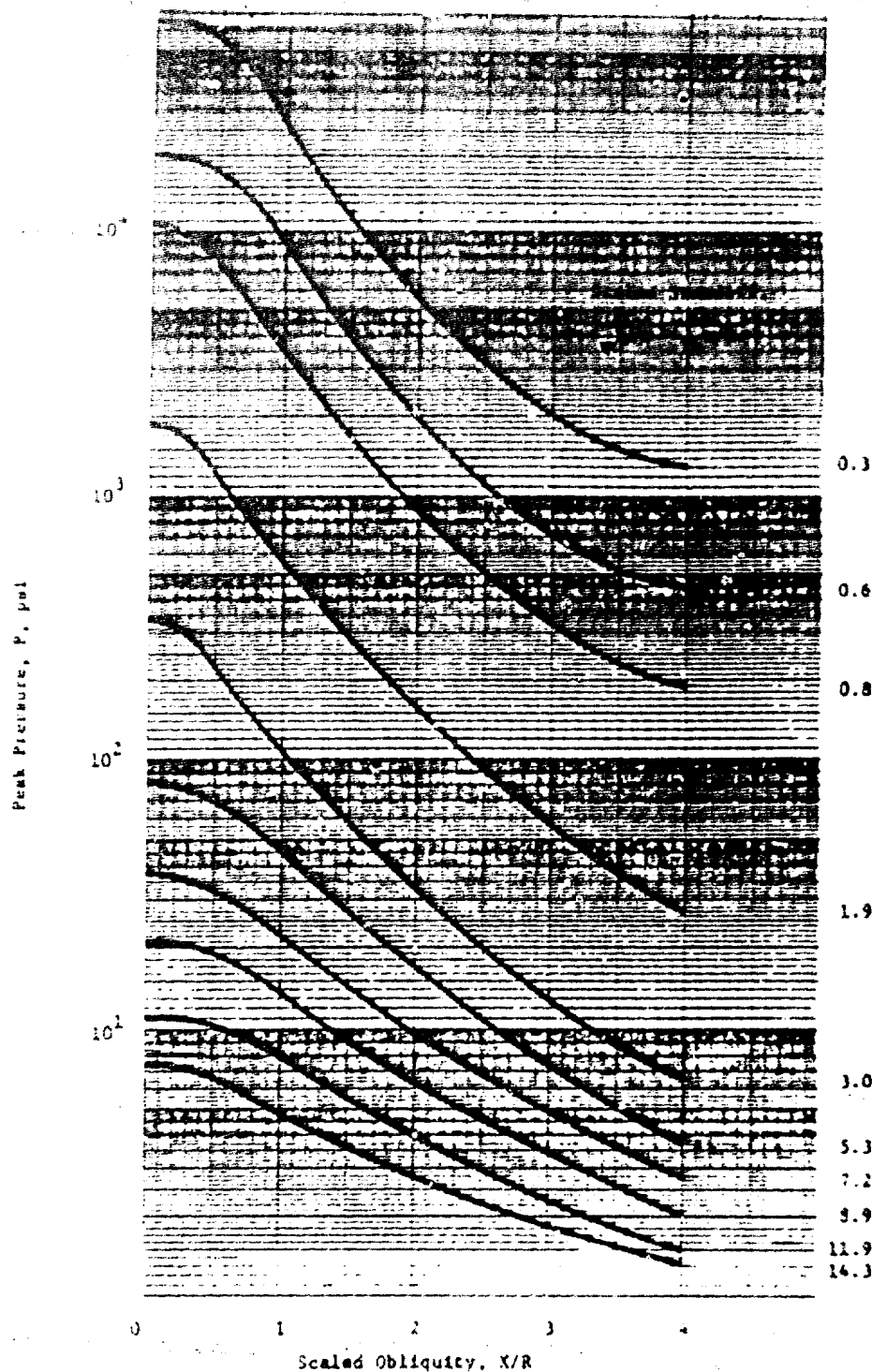
In Chapter 3 the effects of non-ideal blast effects of chemical weapons is analyzed. These include

- Casing about the charge
- Agent about the charge
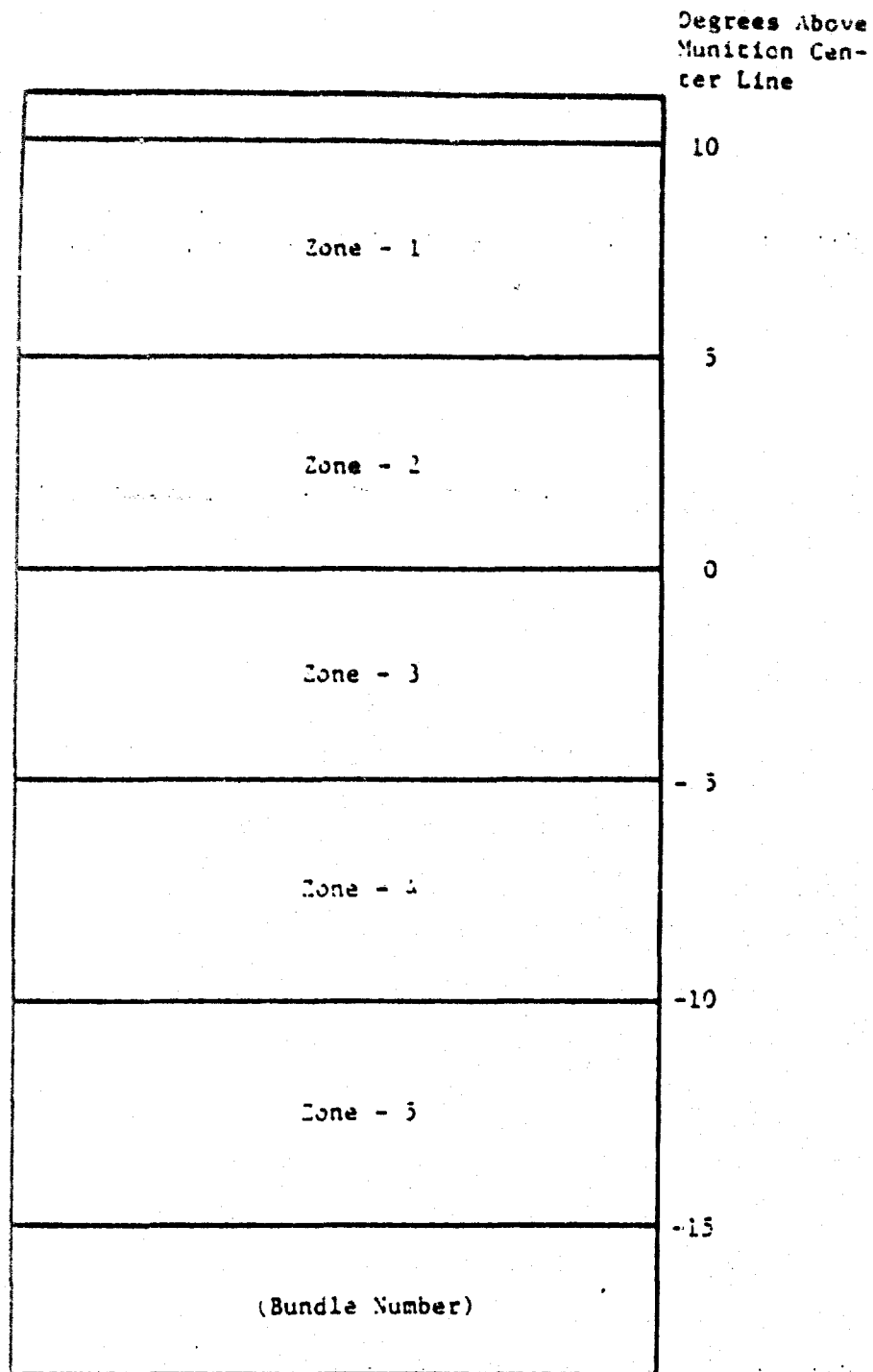
Figure 4. Zone Layout for Each Recovery Bundle

Figure 5.   Peak Pressure for Oblique Shocks for $0 \leq X/R \leq 4$

where R = perpendicular standoff, ft
      X = distance on surface to point of interest, ft
      W = charge weight (TNT equivalent), lb

NOTE: Full-Sized Figures are Attached at End of Report
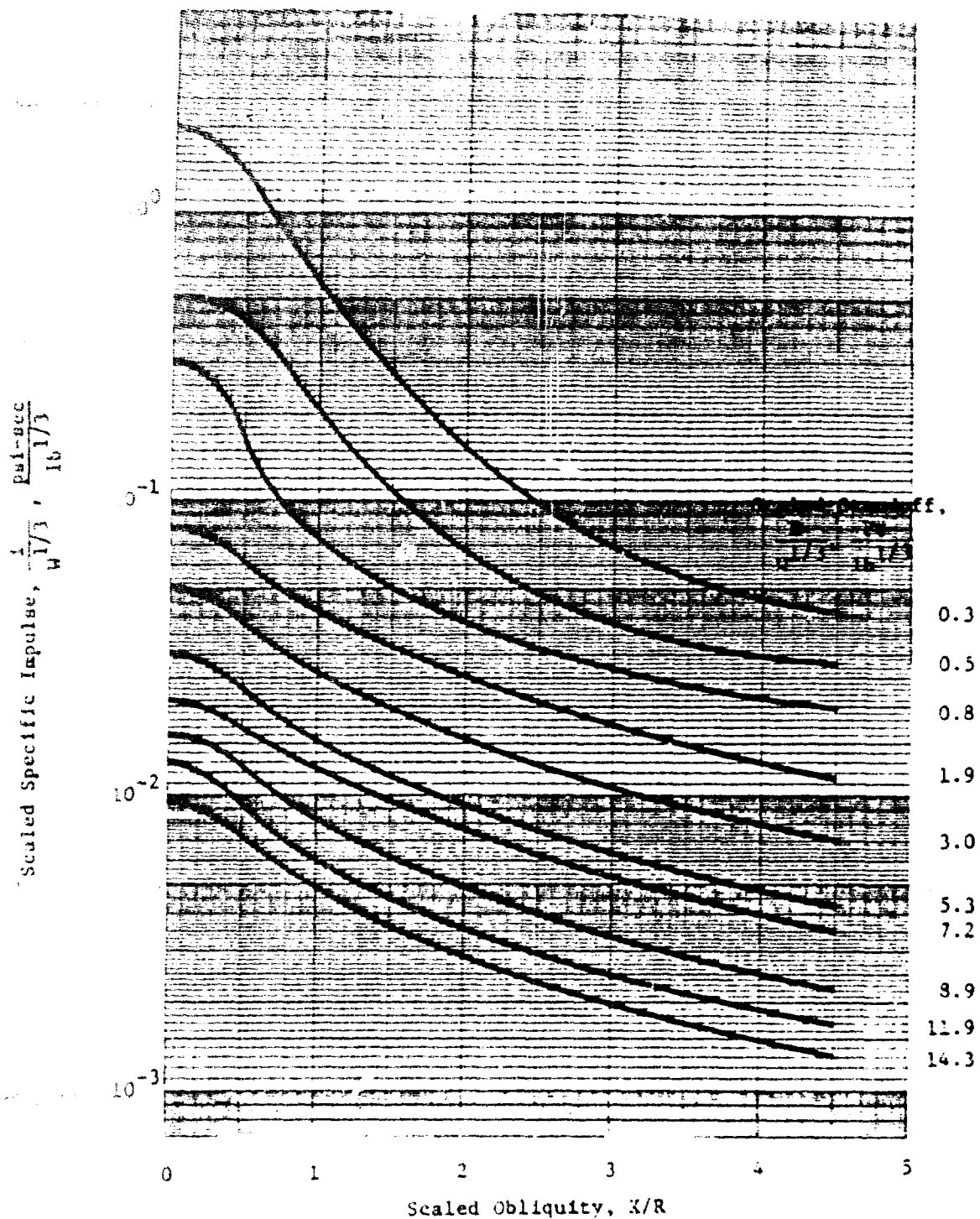
where R = scaled standoff, ft
X = distance on surface to point of interest, ft
W = charge weight (TNT equivalent), lb

NOTE: Full-Sized Figures are Attached at End of Report

Figure 6. Scaled Specific Impulse for Oblique Shocks
for 0 ≤ X/R ≤ 4

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- Shape (cylindrical, large L/D)
- Type of explosive

The data collected during the NSWC testing was analyzed and compared with predictions from air blast curves to determine the best procedure to use.

This chapter includes detailed discussion about the effects of confinement on blast loading. This is an important feature as the chemical weapons will be demiled inside a containment chamber. Finally, a detailed working procedure is given to direct the user in applications.

The second responsibility of Chapter 3 is to provide the designer with the means to predict fragment penetration, perforation, and spall for the worst case fragments identified in Chapter 2. Penetration equations are for fragments into both steel and concrete targets. The limits of applicability of each technique are tabulated for velocity, shape, and material.

Chapter 4 - ECS Loading

In Chapter 4 the blast and fragmentation loading prediction procedures detailed in Chapter 3 are applied to various structural containment shapes. These include the following:

- Rectangular chamber
- Horizontal cylinder chamber
- Vertical cylinder chamber
- Spherical chamber

Blast loads on the following structural elements were predicted to provide the designer example calculations to follow in applications.

- Roof slabs
- Walls slabs
- Ring sections
- End caps
- Spherical elements
- Doors

The fragment penetration equations in Chapter 3 were applied to both steel and concrete materials. The results of both blast and fragmentation loads are summarized along with detailed calculations in Volume II of the manual.

There are many possible configurations and materials of construction for the explosive containment structure (ECS) or chambers. These ir. .de.

a) Horizontal steel cylinder or arch

b) Horizontal reinforced concrete cylinder or arch with or without steel liner

c) Vertical steel cylinder

d) Vertical reinforced concrete cylinder with or without steel liner

e) Reinforced concrete rectangular chamber with or without steel liner

f) Spherical steel chamber

g) Double-walled steel structure with concrete filler - Rectangular configuration

These configurations were examined and compared based upon the following:

- Structural Integrity
- Size Requirements
- Constructability

The advantages and disadvantages of each configuration were listed and three ECS concepts were chosen for a more detailed evaluation inch six. An overview of some of the more important aspects are listed below.

Structural Integrity - A discussion of example existing explosion containment structures, both steel and concrete, is presented in the manual. Many of these structures have been explosion tested or are routinely subjected to internal explosions at research laboratories, References 2 through 12. The conclusion was that structural integrity with containment could be achieved, and analytical methods are available to accomplish this, for any of the configurations.

Size requirements - The ECS configurations must be large enough to surround the work envelope necessary for equipment and work space. The work envelope is sized by the equipment and operational room around these equipment. For purposes of the manual a rectangular work envelope of 25W x 27L x 16H feet was chosen. This is a representative example of an ECR work envelope; actual

sizes for a specific demil system may vary. Rectangular configurations fit
this shape exactly; sphere, cylinder, and arch shapes do not. As an example,
a sphere would have a 40 foot diameter to fit around the work envelope. A
discussion on how the different configurations shapes for containment chambers
would fit into the entire demil facility was made. Rectangular shapes adapt
to a demil facility made of box-shaped rooms with flat floors. This allows
door entry without drops, steps, or false floors in the containment chamber.
Horizontal cylinders and arch shapes are less desirable from this standpoint,
but much more desirable than vertical cylinders and spherical shapes.

Constructability - Fragment perforation has led to very thick wall steel struc-
tures, much thicker than typical pressure vessels. This fact and the size
of the steel configurations would require field erection rather than being
built elsewhere and shipped. The steel thickness are such that considerable
labor is involved including full penetration welds. Reinforced concrete
thicknesses pose no special construction problems. Flat surface forming is
preferred over curved; however, it is possible to construct the concrete cylin-
drical and arch configurations. The location of doors on the various con-
figurations identified can lead to problems such as designed for curved sur-
faces and the presence of stress concentrations about door openings in the
containment shell. Door penetrations on flat surfaces are preferred as is
found with the rectangular and horizontal cylinder shapes (on end walls).

A comparison of the various configurations is provided in Table 1. I:
was determined that none of the curved structures (arch, cylinders, spher.
were suitable for containment of an explosion involving the chemical weap.
understudy. The following concepts were chosen for further study.

- Reinforced concrete rectangular chamber
- Steel rectangular chamber
- Double-walled steel framework rectangular chamber
  with concrete fill.

Chapter 6 - Candidate ECS Conceptual Designs

The three designs chosen in Chapter 5 were analyzed in detail in this
chapter. Construction considerations are discussed along with design meti
and allowable design deflections. A summary of the three designs is prov:
with a complete accounting of all design analysis provided in Volume II.

Table 1.   ECS Concept Evaluation

Configuration	Material	Dimensions (ft)			Volume (ft³)	Surface Area (ft²)	Door On Curved Surface	End Cap Size (ft)	Floor Required	Shape Conform To Rectangular Shaped Facility	Preferred Based On Decontamination
		Length	Width	Height							
Horizontal Cylinder	Steel	27.0	29.7	29.7	18,700	3,920	No	29.7	Yes	No	Yes
Horizontal Cylinder	Concrete	27.0	29.7	29.7	18,700	3,920	No	29.7	Yes	No	No
Horizontal Arch	Steel	27.0	20.3	20.3	17,500	3,017	No	20.3	No	No	Yes
Horizontal Arch	Concrete	27.0	20.3	20.3	17,500	3,017	No	20.3	No	No	No
Vertical Cylinder	Steel	36.8	36.8	16.0	17,000	3,980	Yes	36.8	No	No	Yes
Vertical Cylinder	Concrete	36.8	36.8	16.0	17,000	3,980	Yes	36.8	No	No	No
Rectangular Chamber	Steel	27.0	25.0	16.0	10,800	3,014	No	16.0	No	Yes	Yes
Rectangular Chamber	Concrete	27.0	25.0	16.0	10,800	3,014	No	16.0	No	Yes	No
Rectangular Chamber	Steel Framework	27.0	25.0	16.0	10,800	3,014	Yes	16.0	No	Yes	No
Spherical Chamber	Steel	40.1	40.1	40.1	36,000	5,280	Yes	N/A	Yes	No	Yes
Spherical Chamber	Concrete	40.1	40.1	40.1	36,000	5,280	Yes	N/A	Yes	No	No

designs were taken far enough in detail to provide material quantity survey and cost comparisons.

Conclusions - A manual was developed that provides the designer the capability to predict blast and fragmentation loadings from chemical weapons. Development of possible containment chambers concepts was provided.

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